American Journal of Climate Change, 2023, 12, 172-203
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

Identification of Groundwater Potential Zones in Samendeni Watershed in Sedimentary and Semi-Arid Contexts of Burkina Faso, Using Analytic Hierarchy Process (AHP) Method and GIS

Sadraki Yabre[1,2], Youssouf Koussoubé[2], Sauret Élie Serge Gaëtan[3], Nicaise Yalo[4], Stephen Silliman[1,5]

[1]West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Doctoral Research Program in Climate Change and Water Resources, Institut National de l'eau, Université d'Abomey Calavi, Cotonou, Bénin
[2]Laboratoire Géosciences et Environnement (LaGE), Département des Sciences de la Terre, Université Joseph KI-ZERBO/Unité de Formation et de Recherche en Sciences de la Vie et de la Terre, Ouagadougou, Burkina Faso
[3]Centre National de Recherche Scientifique et Technologique, Institut de l'Environnement et de Recherches Agricoles-Département Gestion des Ressources Naturelles/Systèmes de Productions, DRREA-Ouest, Station de Farako-bâ, Bobo-Dioulasso, Burkina Faso
[4]Laboratoire d'Hydrologie Appliquée (LHA), Institut National de l'eau, Université d'Abomey Calavi, Cotonou, Bénin
[5]School of Science Technology Engineering and Math, Trevecca Nazarene University, Nashville, Tennessee, USA
Email: ysadraki@gmail.com

How to cite this paper: Yabre, S., Koussoubé, Y., Gaëtan, S. É. S., Yalo, N., & Silliman, S. (2023). Identification of Groundwater Potential Zones in Samendeni Watershed in Sedimentary and Semi-Arid Contexts of Burkina Faso, Using Analytic Hierarchy Process (AHP) Method and GIS. *American Journal of Climate Change, 12,* 172-203.
https://doi.org/10.4236/ajcc.2023.121009

Received: December 15, 2022
Accepted: March 28, 2023
Published: March 31, 2023

Abstract

Demand for water increases in Samendeni regarding the undertaken agricultural projects while pressure on surface water from global warming/evapotranspiration also increases. Thus, the need to evaluate the groundwater potential in the catchment is crucial as alternative supplier of water and resilience to climate hazards. The AHP was performed integrating ten influencing factors such as geomorphology, geology, soil, land use/land cover (lulc), slope, rainfall, drainage density, borehole rate & depth and piezometric level to generate groundwater potential zones (GWPZs) in Samendeni watershed (4420 km^2). All the factors were processed and ranged into five (5) classes. Weight was assigned to each class of thematic layer. These thematic layers were then reclassified based on the normalized weight to be used in the calculation of groundwater potential zones (GWPZ). The final output, groundwater potential map, revealed a significant groundwater potential with very good (11%), good (31%), moderate (30%), poor (20%), and very poor (8%) of proportion. The interesting (very good, good) GWPZs in the study area are mostly in the central towards the east. The poor zones in term of groundwater potential are concentrated in the upper west region of the watershed. Besides the cross-validation with the relationship between different groundwater potential zones and the wells available in the study area, the overall accuracy was estimated to 88% provided from the result of the similarity analysis where 22 out of the 25 validation wells match with the expected yield classes of GWPZs. The statistics from that validation revealed the performance of AHP method to delineate groundwater potential zones at catchment level.

Keywords

Climate Change, Resilience, Groundwater Potential, Water Management, Conjunctive Use, AHP, GIS, Samendeni Watershed

1. Introduction

At the present time where water scarcity is considered as capital issue in many nations across the globe, it is important to count groundwater resource to total annual supply. In fact, surface water owes high vulnerability due to global warming and pollution, while groundwater could stand for reliable source of water in term of availability and sustainability over times (Malundama, 2019).

In Sahelian countries, the availability of water resources with regards of quality and quantity remains a great challenge. That is exacerbated by the rapid growth of populations and the knowledge gaps of water resources as well as rainfall hazards. The impacts of global warming pose serious risks to water resources and all the activities and organisations that depend on them. Rural areas are then enduring hard impacts on available water, water supply, food security, infrastructure and agricultural incomes, and displacement of food and non-food crop production areas (IPCC, 2014).

In Burkina Faso, the challenge of water sustainability is significant. The water demand for the various utilizations (domestic, agriculture, livestock, etc.) is relevant at any period in the year. The demand for water is increasing not only because of the rapid growth of the Burkinabe population but also because of the adverse effects of climate change that the country is experiencing. According to the 2006 INSD[1] (2006) survey, the population of Burkina Faso is growing at an annual rate of 3.12%. Hence, climatic variables indicate an average increase in the temperature to 3.6˚C in 2100 (IPCC, 2014). The same source (IPCC) estates that the annual potential evapotranspiration (PET) will increase approximately to 86 mm in 2030 and 215 mm in 2100. Therefore, there is increasing trend of the PET over Mouhoun catchment and a decrease in the river flow of the Mouhoun River (Kouanda, 2019) as well as its mains tributaries such as Kou river (Sauret, 2013). The increasing trend at the Bobo Dioulasso station has already been proven by Tirogo (2016). However, agriculture constitutes about 80% of

[1]Institut National de la statistique et de la démographie.

Burkina Faso's economic activities. That means, water resources are an essential part of the national economy. As a result, programmes were implemented for water utilization such as the construction of Samendeni hydro-agricultural dam on the Mouhoun River, which has a storage capacity of 1.05 billion m^3 to supply big cities like Bobo and Koudougou for drinking water, irrigation zones of 17 thousands hectares distributed into 17 separated sites and electricity production. Knowing that the filling coefficient of the various dams built in the catchment is likely to decrease (Zougmoré et al., 2019); consequently, the water level in the reservoirs will also decrease. However, the availability and quantity of water resources during different parts of the year are of key importance for an agricultural country like Burkina Faso specifically Hauts-bassins region considered as country granary. But regarding the high important role given to water resource in the area and overall in the country, it is relevant to consider both water resources (SW & GW). In fact when water demand cannot be filled by surface water, groundwater is tough supplement to address the scarcity. Groundwater has to be used conjunctively with surface water to supply water demand.

Relative to surface water, aquifers have indeed the capacity to store large volumes of water and are naturally buffered against seasonal changes in temperature and rainfall. They provide a significant opportunity to store excess water during high rainfall periods, to reduce evaporative losses and to protect water quality (Sinclair Knight Merz, 2009). So that in irrigated areas, irrigation water will not only come from rivers, natural and artisanal water bodies but also from boreholes/wells exploiting groundwater aquifer. That will help to reduce vulnerabilities of water supply systems and mitigate the water supply stress in responding to climate change.

Most research to-date has been directed at understanding the hydrodynamic and aquifers potentialities of the region (Dakoure, 2003; Derouane, 2008; 2010; Koussoube, 2010; Huneau et al., 2011; Sauret, 2013; Tirogo, 2016). A global estimation of the potentialities of the aquifers is not thorough enough to attempt exploitation in specific points even if the aquifer belongs to the sedimentary hydrogeology. Generating a groundwater potential map is relevant to identify high-grade sources of groundwater. This has a significant effect to enhance the sustainable management of groundwater resources in the study area. The traditional approaches used to identify, delineate and map the groundwater potential zones are mainly based on ground surveys using geophysical, geological and hydrogeological tools that are generally expensive and time consuming (Jha et al., 2010; Kumar et al., 2005; Mukherjee et al., 2018).

This study applied the analytical hierarchical process techniques (AHP) of SAATY, & Vargas (1980) to delineate the groundwater potential zones (GWPZs) of Samendeni river basin located in the western part of Burkina Faso. This approach is a widely used in the world by many authors to the maping of the groundwater recharge and potentialities (Das & Pardeshi, 2018; Melese & Belay, 2021; Ake, 2018; Thaís et al., 2020; Arulbalaji et al., 2019; Mohamed & Imad, 2021; Abebe, 2021). It is a multi-criteria modelling using influencing factor and frequency ratio in GIS environment. The results of the study provide to PDIS[2] programme reliable sites of drilling to extract groundwater as wells/boreholes and supplement surface water in context of scarcity regarding change climate effects. This comes across as a measure of resilience to change climate and a way of sustaining the large agricultural/irrigation projects in development in the catchment.

2. Study Area

Study watershed lies between Latitude 10˚40'N to 11˚40'N and Longitude 5˚20'W to 4˚20'W (Figure 1). The total areal extent of the study watershed is 4420 km^2, which is located in the western part of Burkina Faso. The study area is delimited along the transboundary perennial river called Mouhoun (former Black Volta) with outlet at the upstream part of Samendeni dam. Mouhoun River and its tributaries are the main drainage system of the basin. More than forty water springs inside the watershed contribute significantly to the hydrological processes in the watershed. The extreme west boundaries of the basin have hilly landscape, whereas the others parts are characterized by relatively flat and gentle plateau. According to Dakouré (2003), Derouane (2008) and Sauret (2013), the study area is entirely in a sedimentary zone and dominated by sandstones. The study

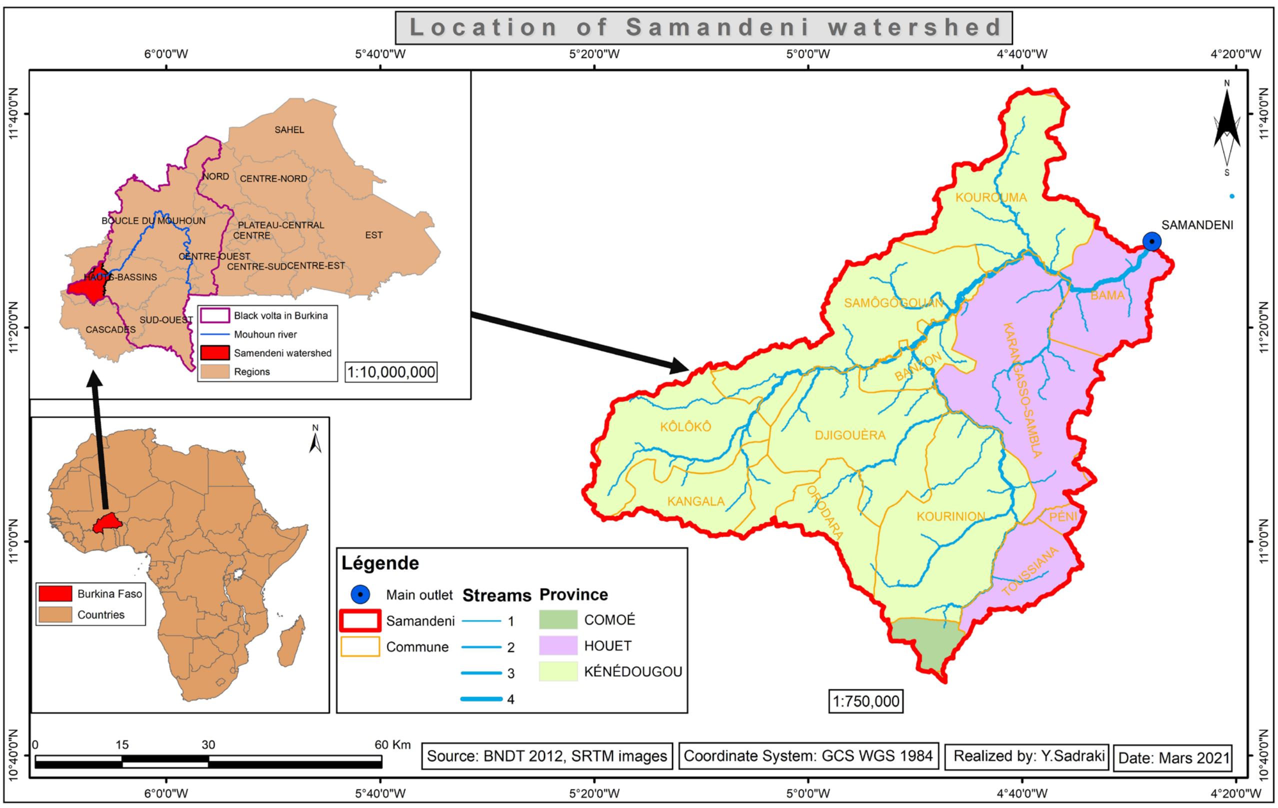

Figure 1. Study area.

[2]Programme de développement intégré de la vallée de Samendeni.

area within the region of "Hauts-Bassins" covers mainly two provinces such as Kenedougou and Houet. More than ten municipality territories are located inside of the watershed. Around forty two (42) springs are identified in the watershed. The water from these springs is considered as lateral flow in the riverbeds of the drainage network.

3. Data and Methods

3.1. Data

In the context of identifying potential groundwater aquifers, the work of several authors (Detay & Poyet, 1991; Savané, 1997; Youan et al., 2011; Babayé, 2012; Hyann et al., 2015; Youan et al., 2015; Koffi, 2016; Yao et al., 2016; Boko et al., 2017; Abdou Ali et al., 2018; Fabrice et al., 2020; Akokponhoue et al., 2019; Saïdou et al., 2019) were synthesized and used to define the criteria for the thematic maps.

Haouchine et al. (2010) and Sekoube et al. (2014) have recognized soil types, LULC, geology, slope and drainage density as factors that contribute to the definition of potential aquifer zones at the regional scale in the sedimentary context. These are a wide range of parameters relating to environmental characteristics and hydrological processes. Saley (2003) and Koudou et al. (2013) add to the previous the map of weathering, permeability and alteration thickness maps, adapted for basement areas. In Burkina Faso, numerous studies and research findings have identify parameters giving good understanding of drilling productivity in crystalline context. There is about weathering level, soil surface conditions, geophysical signatures, etc. (Savadogo, 1984; Nakolendoussé, 1991; Koussoubé, 1996; Kafando, 2020).

Considering these previous researches and the availability of the data for this study area, it has been used a total of ten databases such as geomorphology, geology, soil, land use/land cover (lulc), slope, rainfall, drainage density, borehole yield & depth and piezometric level to delineate groundwater potential zones in Samendeni watershed. All data had been prepared in GIS software. The databases used to generate the ten thematic layers are given in **Table 1**.

3.2. Methods

The Analytical Hierarchy Process (AHP) technique as described by Saaty & Vargas (1980) was applied in this study, and the detailed approach is presented in **Figure 2**. The relevant datasets gathered were processed and weighted using the AHP. All the themes were ranged into five (5) classes and weight was assigned to each class of thematic layer. These thematic layers were then reclassified based on the normalized weight to be used in the calculation of groundwater potential zones (GWPZ) by weights summation.

Flowchart of methodology

Data processing used remote sensing tools such as Google Earth Engine and

Table 1. Data used in this study with respective sources.

Factors	Scale/resolution	Date	Source
Geomorphology	1:200,000	2014	IGB (Institut géographique du Burkina), BNDT (Base nationale des données territoriales)
Geology	1:200,000	2018	BUMIGEB (Bureau des mines et de la géologie du Burkina), mission Giovenazzo
Slope	30 m	2003	Google Earth Engine, SRTM
Rainfall	1000 m	2020	ANAM (Agence nationale de la météorologie)
Soils	500 m	2012	BUNASOLS (Bureau National des Sols)
Land use/land cover (lulc)	30 m	2020-10-28	LANDSAT 8, Google Earth Engine [LC08/C02/T1_L2/LC08_197052_20201028]
Piezometric level	172 wells	2004-2016	DGRE/DEIE, Regional agency in Bobo
Borehole flow rate	172 wells	2004-2016	DGRE/DEIE, Regional agency in Bobo
Borehole depth	172 wells	2004-2016	DGRE/DEIE, Regional agency in Bobo
Drainage density	1:200,000	2014	IGB (Institut géographique du Burkina), BNDT (Base nationale des données territoriales)

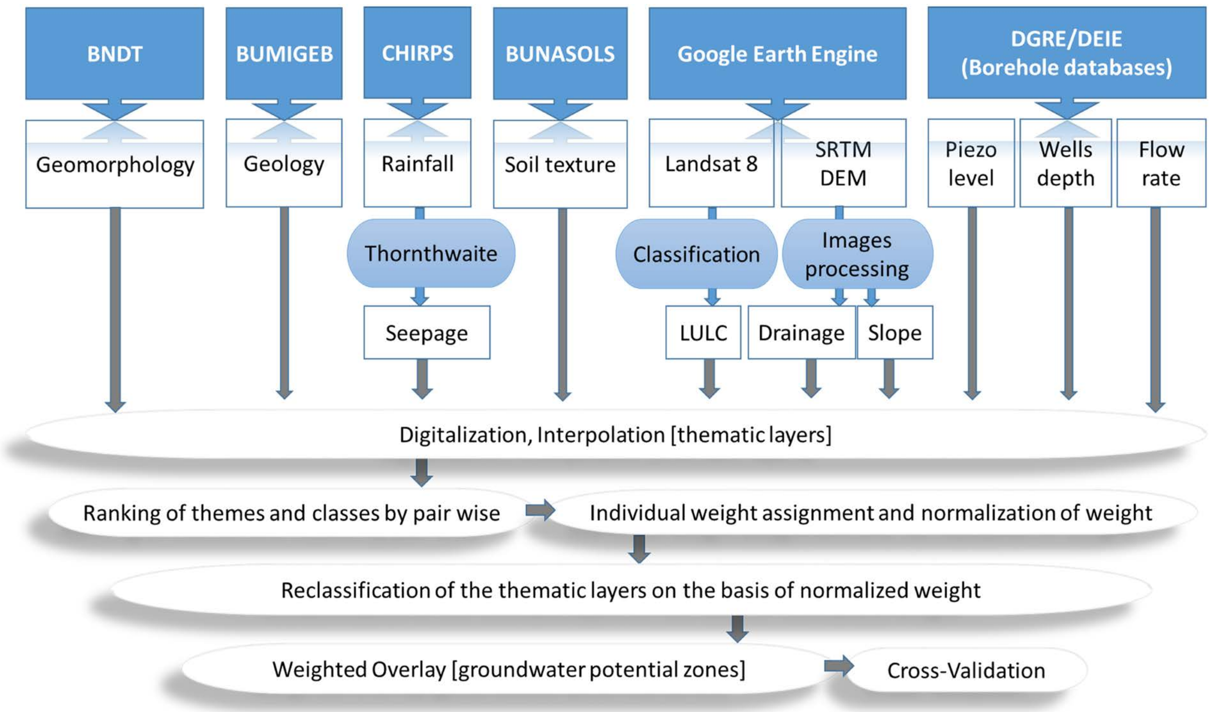

Figure 2. Flowchart of methodology.

GIS environment (Qgis, Arcgis). AHP technique is a very useful method as it is less expensive and very much suitable for developing countries where adequate and good quality data are lacking for this type of evaluation (Ahmed Gaber et al., 2020). To obtain GWPZs using the AHP, this study comprises of ten thematic maps.

3.2.1. Preparation of Factors Controlling Groundwater Potential

This study involves mapping of different features that influence groundwater potentiality in different degrees. Thematic layers viz. geomorphology, geology, LULC, soil, slope, rainfall, drainage density, borehole yield & depth and piezometric levels of the study area were obtained from various sources for processing and integrating to get the GWPZs.

Geomorphology data was collected from the national territorial database (BNDT) realized by Burkina Geographic Institute in 2014. The data is obtained in shapefile format which has been rasterized and reclassified on the basis of the given weights using AHP technique.

Geological data is provided by the Bureau of Mines and Geology (BUMIGEB). It is composed of a mosaic of seven tiles of 1˚ × 1˚ data covering the watershed. The data is at the scale of 1/200,000. After rasterization, data was reclassified into five classes of geology. For each class, a weight has been assigned regarding its contribution to the groundwater potential.

LULC map data was derived from the Landsat 8/OLI satellite image of 2020 with 30-m spatial resolution. Google Earth Engine (GEE) Random Forest method was conducted to classify and identify the type of land use/land cover.

Soils data was obtained with the National Bureau of Soils (BUNASOLS) with 500-m spatial resolution. The transformation made with this data consisted of rasterization and reclassification on the basis of assigned weight to each theme of the five classes.

Slope describes the ruggedness of the terrain of the watershed. A large volume of runoff and lower infiltration are related to regions with steep angles of elevation (Singh et al., 2018). Slope of the study watershed was calculated from SRTM DEM as well drainage network knowing that both affect runoff and infiltration rate. The drainage density, integrated in the calculation of GWPZ, was calculated using line density tool in ArcMap. The drainage density equals the total length of all the streams and rivers in the watershed divided by the total area of drainage watershed. It has an inverse relationship with groundwater prospect. The higher the drainage density is the lower the probability of groundwater potential zone (Choudhari et al., 2014). Weights for each slope drainage density class were assigned based on the level of influence on runoff and infiltration rate.

Rainfall is one of these important factors affecting the groundwater potential and availability. Regarding the good correlation (85%) between CHIRPS and observed rainfall data, and the disability to get enough observation data in the study area, chirps satellite data of rainfall of year 2020 were used for the purpose of this study. Hence, Thornthwaite method has been implemented in Excel to derive the seepage water which is the fraction of rainfall that goes through the subsurface material by seepage to recharge groundwater. Seepage water is calculated directly from the climatic parameters and the useable ground reserve (RFU). $Qseep = P - Q_R - AET - RFU$; with Qseep: Rainfall seepage water, Q_R: surface runoff, P: Precipitation, AET: Actual evapotranspiration, RFU: useable water in ground collected from BUNASOLS (Source: Thornthwaite method).

The following three influencing factors such as depth to water table (piezometric) level, borehole flow rate and depth were provided by two hundred and forty-five (245) boreholes from the national database.

Before proceeding to the maps elaboration, all the thematic layers have been converted into a same cell size (30 m) and same UTM zone 30 P, as the validity of the maps relies upon the scale and selection of UTM zone. Each factor has been rasterized and reclassified in five classes on the basis of assigned weight. Rasterized factors have been generated by the inverse distance weighting (IDW) interpolation method.

3.2.2. Factors Classification and Standardization

The ten factors were identified and classified based on expert opinion and literatures for similar studies (Sekoube et al. 2014; Affoué et al., 2016; Koffi, 2016; Yao et al., 2016; Boko et al., 2017; Ake et al., 2018; Abdou Ali et al., 2018; Fabrice et al., 2020; Akokponhoue et al., 2019; Kafando, 2020). The influence of the factors or themes factors on the productivity of the wells/boreholes using weights was determined by the approach from the perspective of experts. The survey was addressed to factors revealing groundwater potential in basement domain. Based on scores given to these studies, assigned weights are applied to the current factors of this present study. Standardization was used to normalize the factors as they were measured on different scales and in different units. Thus, a common interval from 1 to 10 was used where the most favourable class to groundwater productivity was scored 10 and the least favourable class was scored 1 (**Table 2**).

3.2.3. The Analytic Hierarchy Process (Saaty, 2008)

The following steps are needed to make a decision in an organised way:

1) Define the problem and determine the kind of knowledge sought.

2) Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective to the lowest level.

3) Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.

4) Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Then for each element in the level below add its weighed values and obtain its overall or global priority.

There is a scale of numbers that indicates how many times more important or dominant one factor is over another factor with respect to the criterion or property with respect to which they are compared to make comparison. **Table 3** exhibits the scale.

3.2.4. Factors Weighting and Pairwise Comparison

The decision factors are weighted using the linear combination method based on the Analytical Hierarchy Process (AHP) technique of Saaty (1977). The pair wise comparison was done between the identified ten influencing factors by giving an appropriate score based on the contribution of a factor in comparison with the

Table 2. Assigned and normalized weight of the different classes of each factor and theme.

Recharge parameters	Classes	Degree of contribution	Assigned weight	Normalized weight (Subcategories)
1. Geomorphology	Outcrops of bedrock	Very poor	1	0.08
	Lowland	Very high	7	0.26
	Cuirass	Poor	3	0.11
	Sandstone shelf	Medium	5	0.19
	Water bodies	High	10	0.37
2. Geology	Dolerite	Poor	3	0.19
	Pink fine sandstone	Medium	5	0.31
	Quartz granulated sandstone	High	7	0.44
	Siltite, argillite, carbonate	Very poor	1	0.06
3. Soils	Fersiallitic soils	High	7	0.24
	Hydromorphic Soils	Poor	3	0.10
	Mineral Soils	Very poor	1	0.03
	Poorly developed soils	Very poor	3	0.10
	Soils of Mull	Medium	5	0.17
	Sesquioxides and mineralised organic	Very high	10	0.34
4. LULC	Water bodies	Very high	10	0.38
	Build up	Very poor	1	0.04
	Crops	Medium	5	0.19
	Vegetation cover	High	7	0.27
	Bare areas	Poor	3	0.12
5. Piezometric levels (m)	0.85 - 11	Very high	10	0.38
	11 - 16.62	High	7	0.04
	16.62 - 26.51	Medium	5	0.19
	26.51 - 40.43	Poor	3	0.27
	40.43 - 79.70	Very poor	1	0.12
6. Borehole flow rate (m^3/h)	0 - 3	Very poor	1	0.04
	3 - 5	Poor	3	0.12
	5 - 10	Medium	5	0.19
	10 - 15	High	7	0.27
	15 - 73	Very high	10	0.38
7. Borehole depth (m)	0.3 - 50	Very high	10	0.38
	50 - 60	High	7	0.27
	60 - 75	Medium	5	0.19
	75 - 100	Poor	3	0.12
	100 - 228	Very poor	1	0.04

Continued

8. Slope (%)	0 - 2	Very high	10	0.38
	2 - 4	High	7	0.27
	4 - 8	Medium	5	0.19
	8 - 12	Poor	3	0.12
	12 - 38	Very poor	1	0.04
9. Drainage density (km^{-1})	0.28 - 0.56	Very poor	1	0.04
	0.56 - 0.86	Poor	3	0.12
	0.86 - 1.20	Medium	5	0.19
	1.20 - 2.16	High	7	0.27
	0.28 - 0.56	Very high	10	0.38
10. Seepage water (mm)	12 - 15	Very poor	1	0.04
	15 - 25	Poor	3	0.12
	25 - 35	Medium	5	0.19
	35 - 45	High	7	0.27
	45 - 51	Very high	10	0.38

Table 3. The fundamental scale of absolute numbers.

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	A reasonable assumption

peer factor to groundwater storage or potential. The pair wise comparison gives the ratio of importance between the factors. For example, factor 3 is worth 1/3 of factor 1, because its scores are three times less important than the score of factor 1 in the accumulation of groundwater. The geometric mean which is the average performance of the series of scores was used to derive normalized weight for each factor. It results in standardised weighting coefficients that sum to 1. The result of the weighting of the identified factors, the combination of which contributes for good or bad groundwater storage, is recorded in Table 4.

3.2.5. Factors Aggregation

This involves multiplying each factor by its respective weight and then summing these results to produce a fitness index according to:

$$S = \sum_{i=1}^{n} w_i x_i$$

where S is the final score; w_i is the weight of the factor i; and x_i is the standardised value of the factor i.

The generation of the thematic map "groundwater potentiality" consists of plotting the different values resulting from the summation of the standardised and weighted values. A reclassification of the factors will lead to thematic maps with five classes: very poor; poor; moderate; good and very good.

4. Results and Discussion

Ten different influencing factors such as geomorphology, geology, LULC, soil, slope, rainfall, drainage density, borehole yield & depth and piezometric levels are used to demarcate groundwater prospect zones in Samendeni watershed. The final calculation for GWPZs identification used normalized weights in the AHP model.

Table 4. Pair wise comparison and calculation of normalized weights.

Factors	Geom	Geol.	Soils	LULC	Slope	Drain.	Yield	Piezo	Depth	Seep.	Geometric mean	Normalized weight
Geom.	1	1/3	1/5	1/5	1/3	1/3	1/9	3	5	1/9	0.44	0.03
Geol.	3	1	1/3	5	3	3	1/5	3	5	3	1.82	0.12
Soils	7	3	1	3	1/3	5	1/7	5	7	1/5	1.59	0.10
LULC	5	1/5	1/3	1	1/3	3	1/5	5	3	1/5	0.85	0.06
Slope	3	1/3	3	3	1	5	1/5	3	5	1/3	1.46	0.10
Drainage	3	1/3	1/5	1/3	1/5	1	1/7	5	3	1/5	0.60	0.04
Seepage	9	5	7	5	5	7	1	9	9	3	5.16	0.34
Piezo.	1/3	1/3	1/5	1/5	1/3	1/5	1/9	1	1/3	1/9	0.26	0.02
Depth	1/5	1/5	1/7	1/3	1/5	1/3	1/9	3	1	1/9	0.29	0.02
Flow rate	9	1/3	5	5	3	5	1/3	9	9	1	2.81	0.18
					Sum						15.28	1.00

4.1. Thematic Maps of Influencing Factors

Geomorphology

The Geomorphology of the study area display five major geomorphic divisions: bedrock outcrops, cuirass of laterite, water bodies, lowlands and plateau of sandstone (**Figure 3**). The sandstone plateaus are the widely represented in the watershed. The bedrock outcrops surround the borders of the study area. The laterite cuirasses are the less important in the watershed.

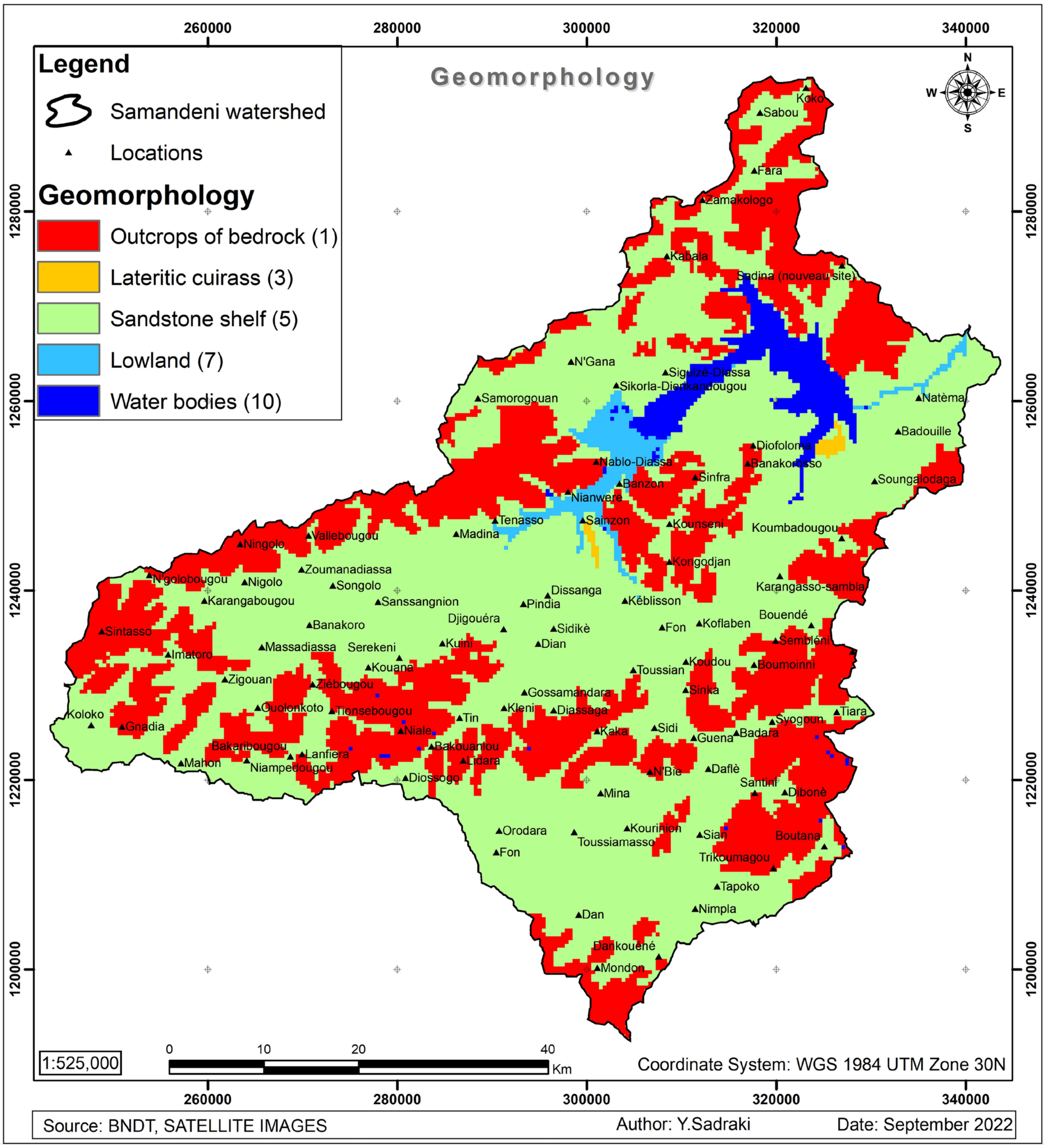

Figure 3. Geomorphology map of the study area.

Geology

Pink sandstone occupies the middle part of the watershed closed to the north (**Figure 4**). Dolerite occurs almost everywhere inside the watershed in small size. Siltite, argillite and carbonate are the main lithology present in the watershed at the central and extreme north part. Sandstone with quartz is located in the southern part.

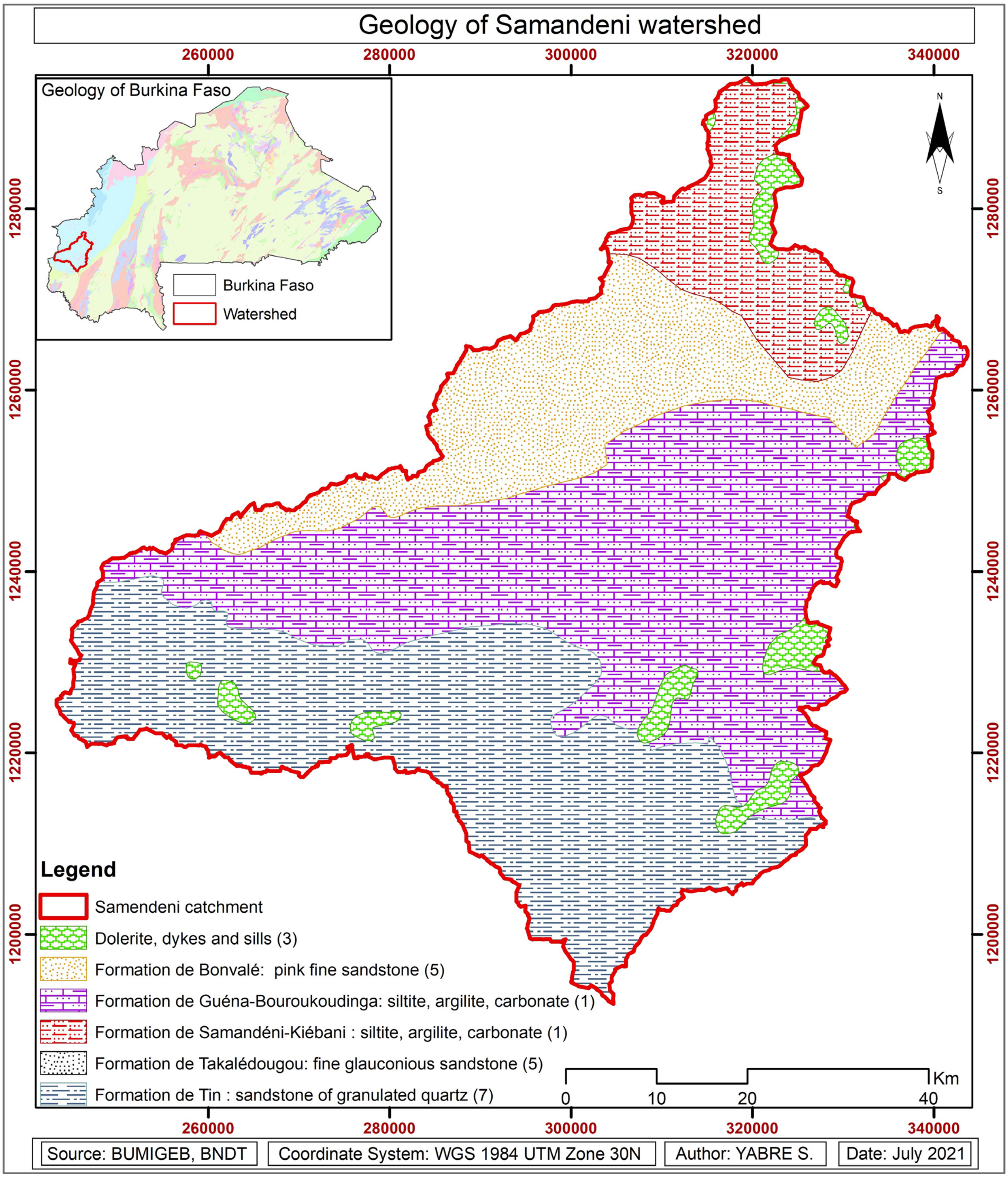

Figure 4. Lithology of the study area.

Soils

Soils texture found in the study area is ranked into five (5) classes: fersiallitic soils, hydromorphic soils, mineral soils, poorly developed soils, mulls soils, soils with sesquioxides and organic matter. The nature and thickness of soils are important because the infiltration from rainfall to aquifers relies on them. Each class is characterized by its role in groundwater accumulation (Figure 5).

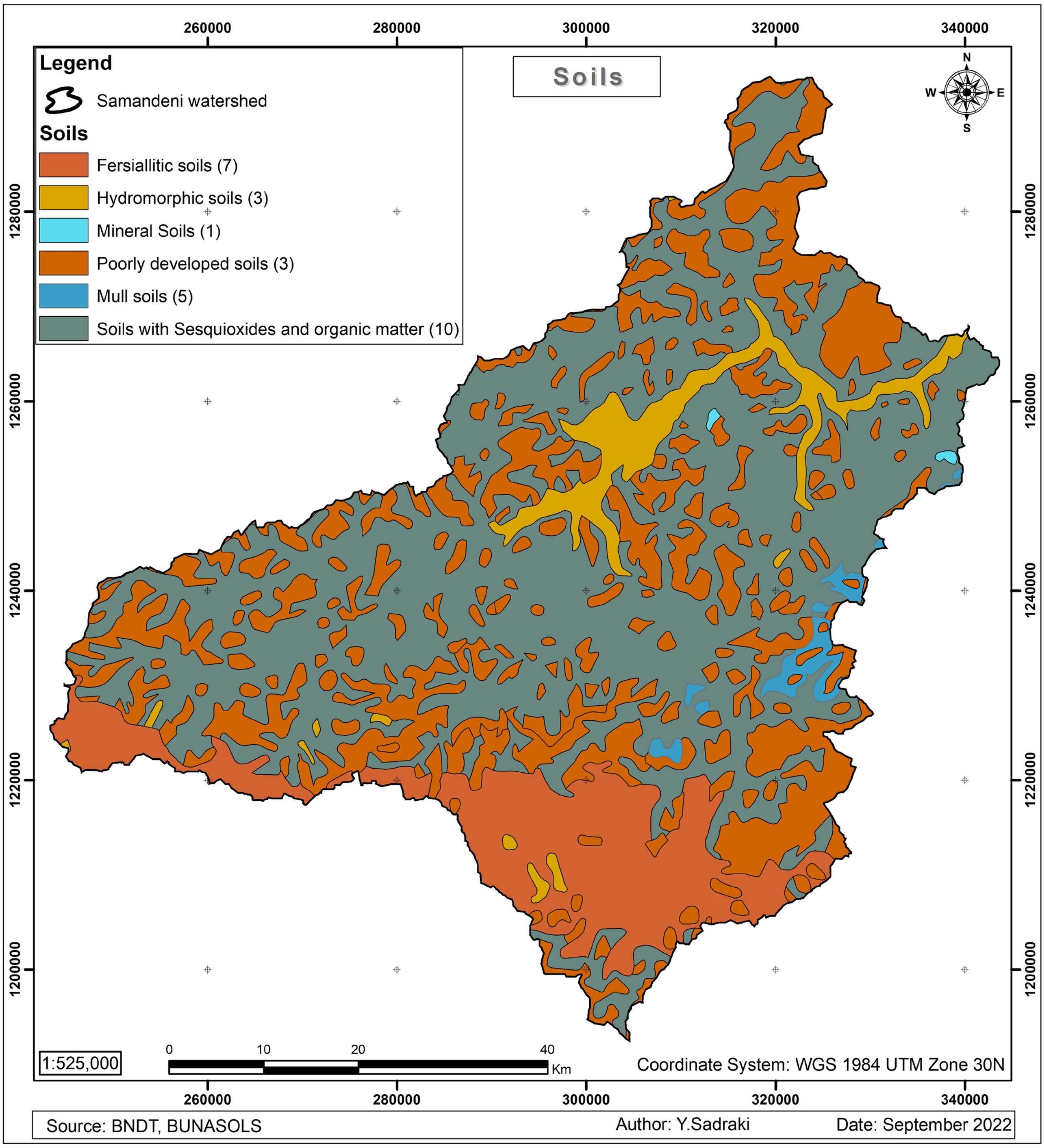

Figure 5. Soils map of the study area.

Land use/land cover (LuLc)

LULC patterns in the Samendeni watershed are barelands (23.3%), natural vegetation (27.15%), cropland (43.98%), built-up (0.68%) and water bodies (2.89%) (Figure 6). Regions with very high built-up and concrete constructions are bad for groundwater potential because of more surface run-off similarly to barelands, while croplands are good due to the availability of loose soil on the surface (Singh et al., 2018; Das & Pardeshi, 2018). Vegetation coverage give a detention capacity to the ground what increases the infiltration. Moreover, surface water bodies are sources to groundwater storage.

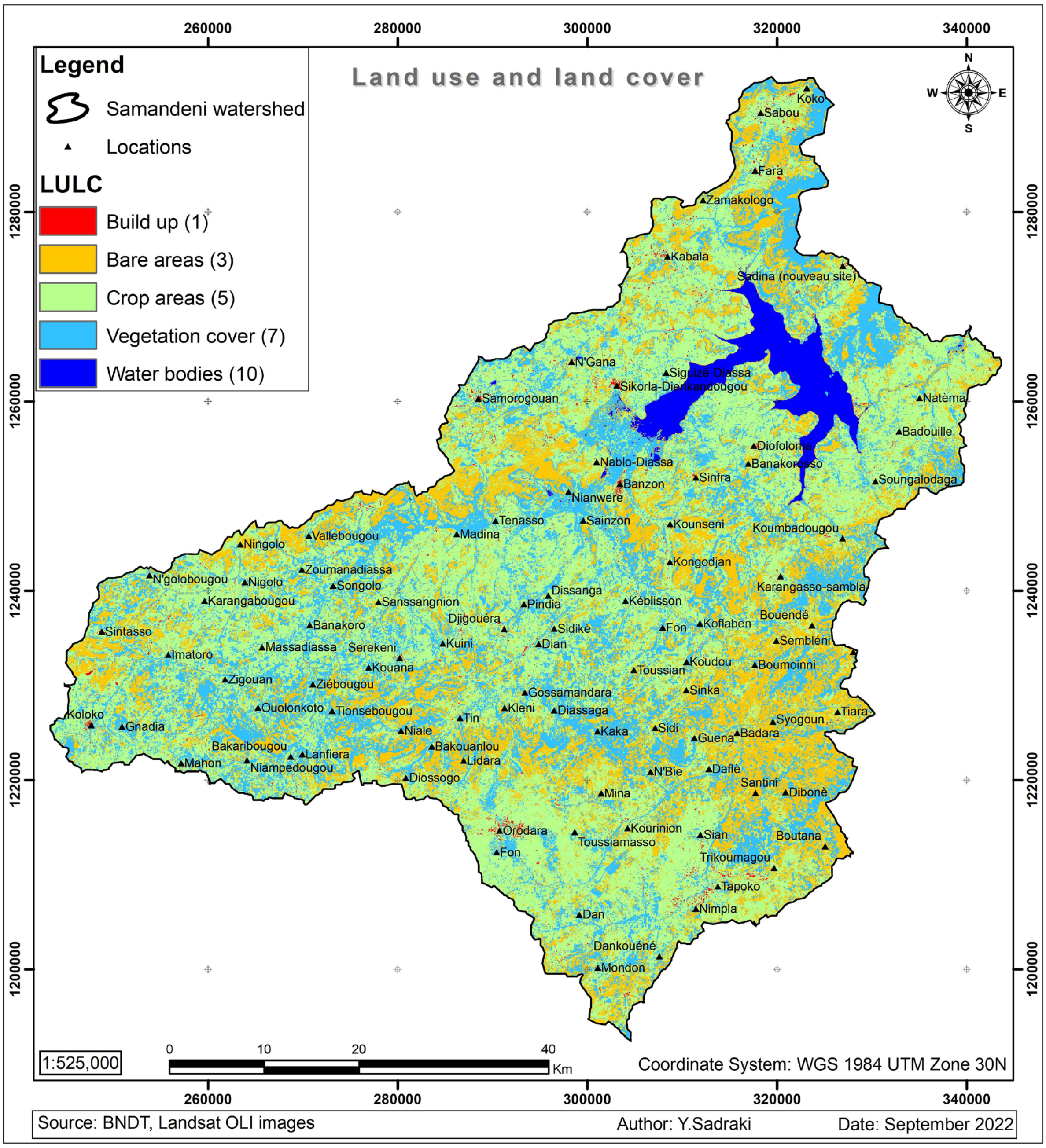

Figure 6. Land use/land cover of the study area.

Slope

Slope controls the groundwater potential in so far as rapid run-off occurs in the case of steep slope due to the higher velocity of the water. In the gentle slope region, the water becomes stagnant in a particular place for a longer duration which influences water to penetrate into soil layers (Das & Pardeshi, 2018). The range of slope in Samendeni watershed is from 0˚ to 38˚. The classes of slope contributing differently to groundwater accumulation inthe catchment are 0˚ - 2˚; 2˚ - 4˚; 4˚ - 8˚; 8˚ - 12˚ and 12˚ - 38˚. Respectively the first class is privileged slope enabling excellent groundwater accumulation due to the flat terrain. While the last class representing high and steep negatively impact the groundwater accumulation from rainfall seepage. That means higher is the slope, less it contributes to groundwater accumulation and vice versa (**Figure 7**).

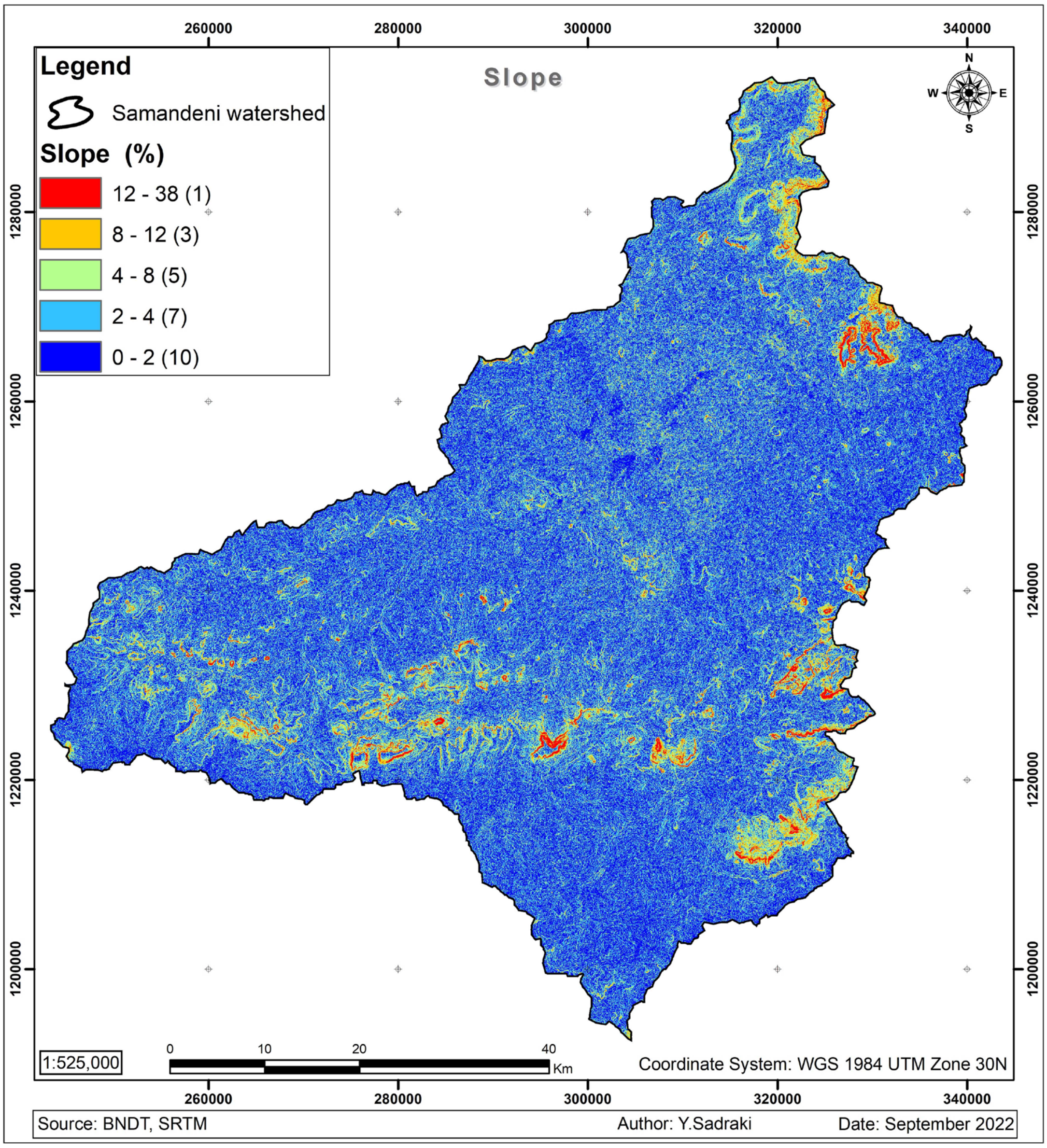

Figure 7. Slope of the study area.

Drainage density

The drainage density has an inverse relationship with groundwater prospect. The higher the drainage density is the lower the probability of groundwater potential zone (Choudhari et al., 2014). The map shows that the study area is dominated by moderate to high drainage density that limits infiltration and recharge rate. Figure 8 shows the five classes of the drainage density of Samendeni watershed.

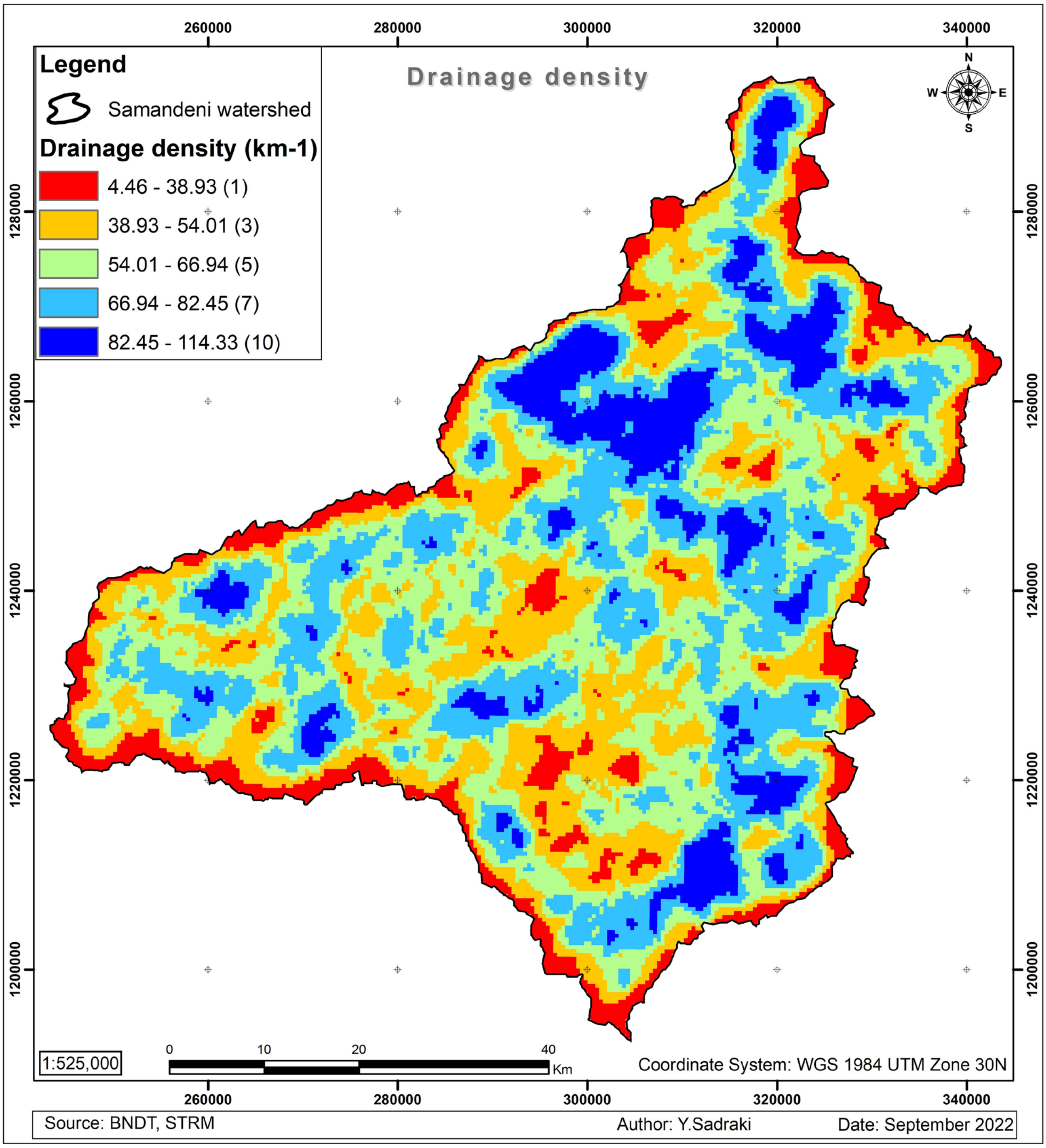

Figure 8. Drainage density of the study area.

Boreholes yield

The minimum yield that produces the existing boreholes in the study area is 1 and the maximum is set at 50 m^3/h. The calculated mean of yield gives 7 m^3/h. This value is confirmed by the map where the class 5 - 10 m^3/h is the widely represented. From 5 m^3/h and more are significant and very useful in irrigation purpose. The high values are majorly located in the north and north central part of the watershed (Figure 9).

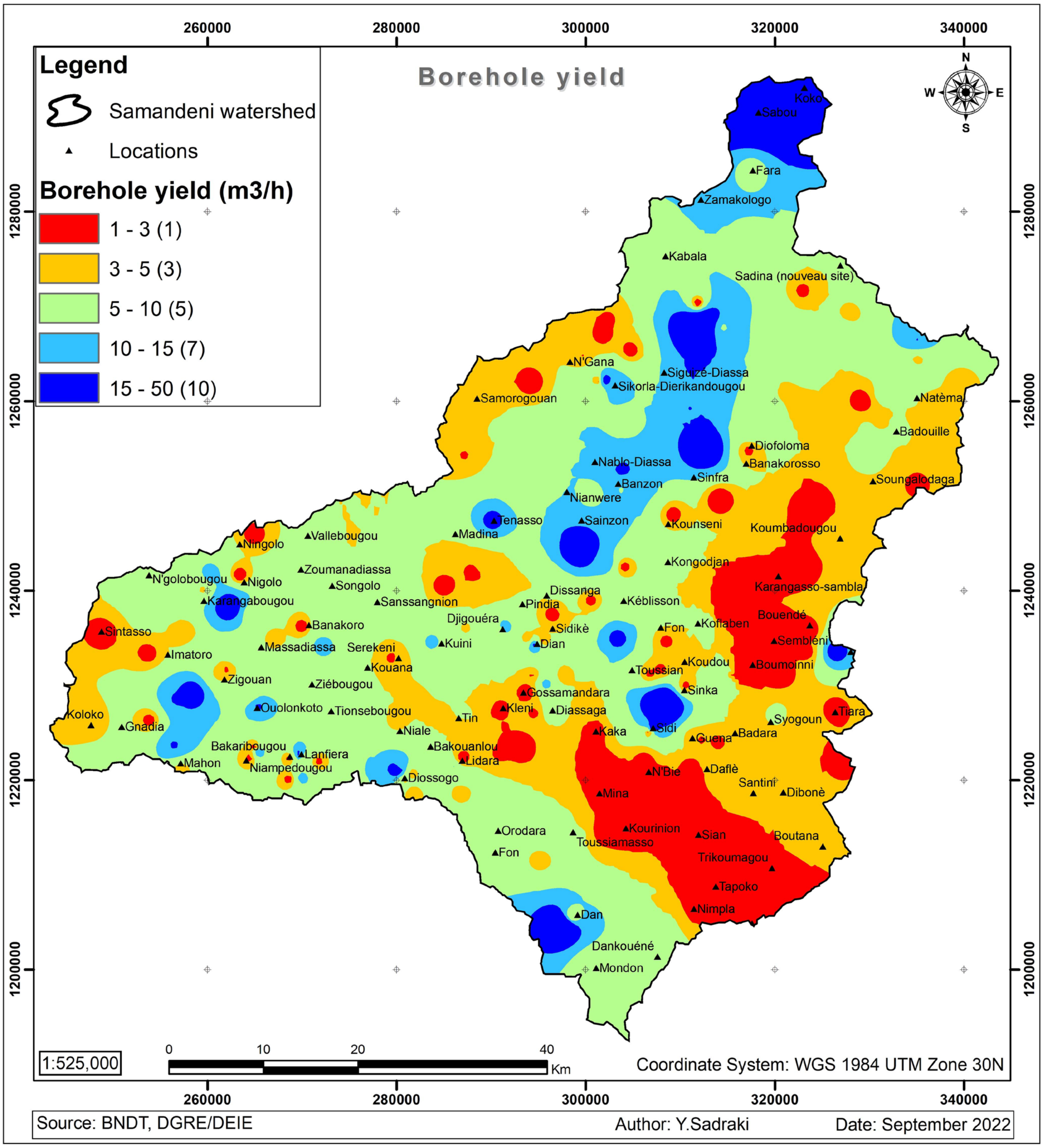

Figure 9. Boreholes flow rate of the study area.

Borehole depth

The depths map shows a moderated distribution of each ranked class. The low depth expresses the abundance of the groundwater in the zone. Deep borehole translates the difficulty to access to its water. In the study area, a relative accessibility to groundwater regarding the low depth of the boreholes was observed (Figure 10).

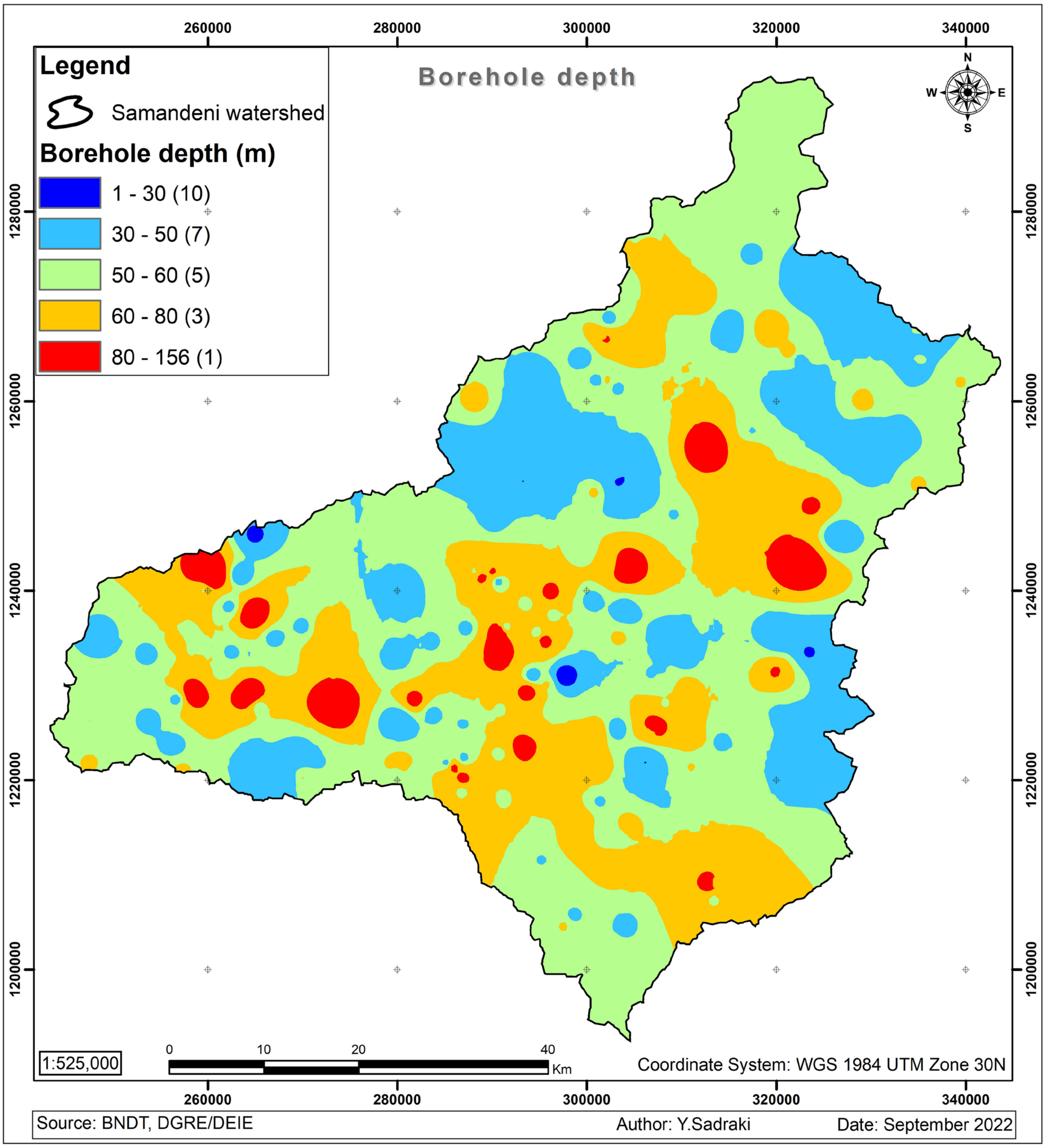

Figure 10. Boreholes depth in the study area.

Depth to the water table level

The measured water table head or piezometric levels in the wells in Samendeni watershed vary from 0.85 to 80 m. Lower is the depth to the water table great is the expectation for groundwater availability in the well. The high depth evokes water scarcity and accessibility issue. But the most in the study area gives a groundwater head heighted from 5 to 15 (Figure 11).

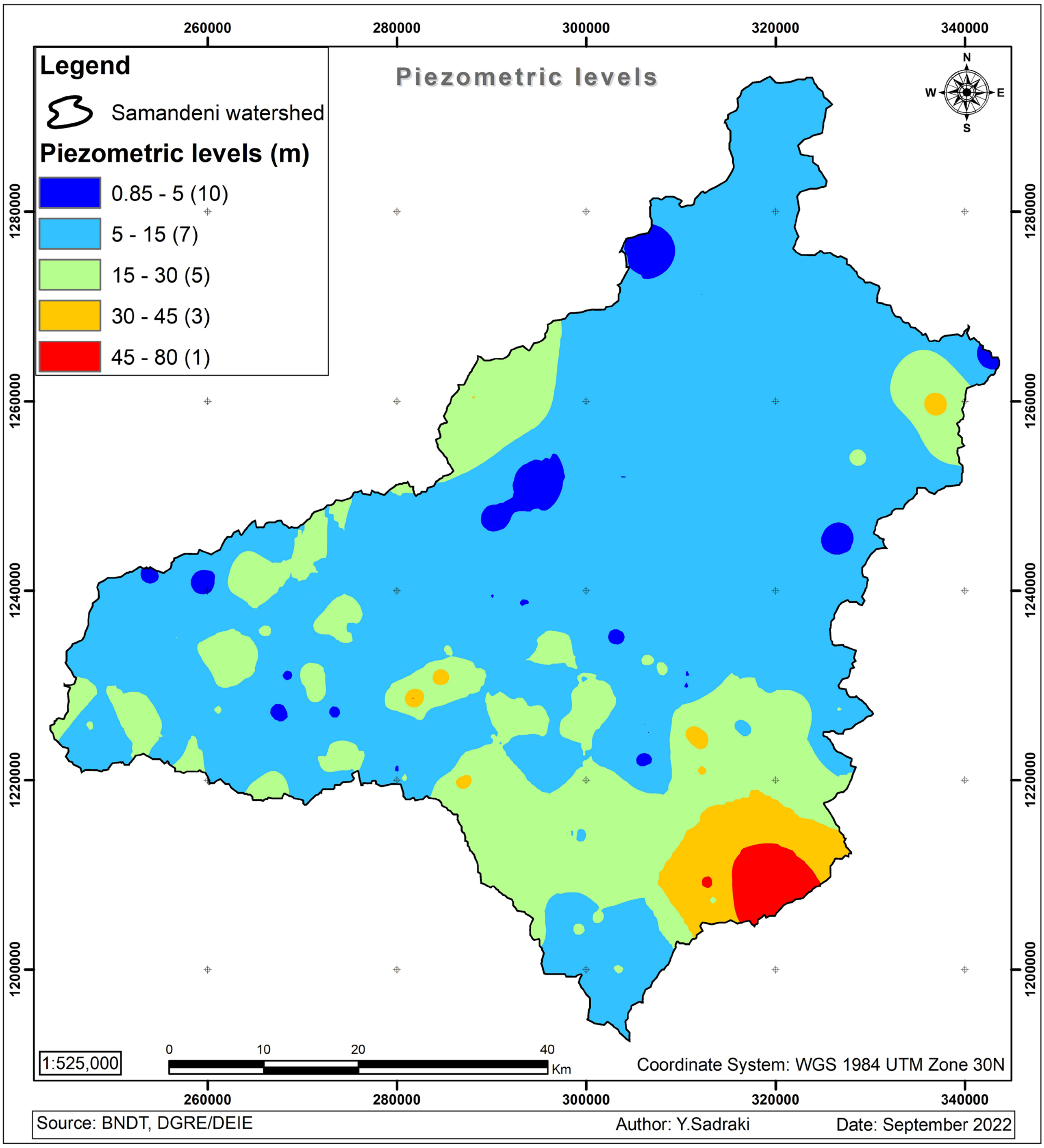

Figure 11. Depth to water table in wells of the study area.

Seepage water

Rainfall is the major water source in the hydrological cycle and the most dominant influencing factor in the groundwater of an area (Arulbalaji et al., 2019). Obviously, the calculation of normalized weight in **Table 4** shows that seepage carries the high weight (0.34). The seepage is assumed being the part of rainfall that really reaches the aquifer. The seepage water map gives values between 12 to 51 mm. This result is relatively closed to the recharge value of Kouanda (2019) applying the method of Conductivity Mass Balance (CMB) in the same study area (**Figure 12**).

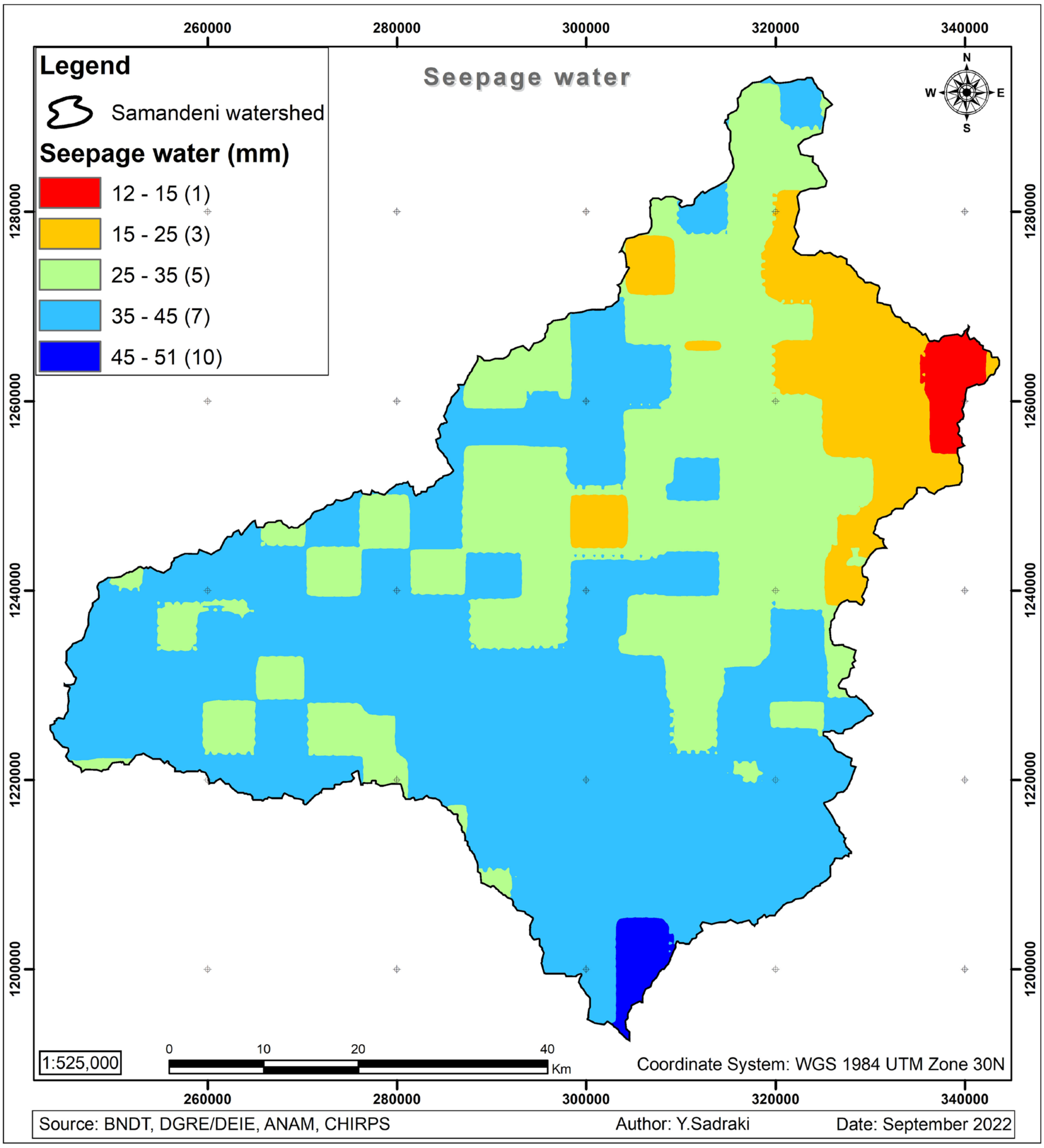

Figure 12. Seepage water of the study area.

The GWPZ as final result of the study overlays all the previous thematic maps in ArcGIS.

4.2. Groundwater Potential Zones (GWPZs)

The AHP was performed integrating all the ten influencing factors to generate groundwater potential zones (GWPZs) in Samendeni watershed. The final output is ranked into five (5) zones based on Natural Breaks (Jenks) method: very poor, poor, moderate, good, very good. The groundwater potential map (**Figure 13**) shows a significant groundwater potential given that zones of good to excellent potentiality cover 42% of the watershed area. The interesting (good and very good) GWPZs in the study area are mostly located in the central going eastwards. The poor zones in term of groundwater potential are concentrated in the upper west region of the watershed. The main factors influencing groundwater potential in Samendeni basin are slope, seepage intensity, lithology and wells flow rate. There is likely a preference for flat areas regarding the interesting GWPZs while there is none significant distinction for the lithology. However, it is remarkable that the interesting GWPZs owning large areas are situated in both sandstones lithology. The different GWPZs are strongly related to the relevant classes of seepage intensity. That could explain a direct recharge of aquifers from rainfall and a roleless of surface runoff in the accumulation of groundwater in the study area.

The very good potential zone covers 11% of the total area of Samendeni watershed. The areas of this class are mainly identified within Kourinion, Djigouera, Koloko, Banzon and Samogogouan. The zone of good potentiality is the most represented (31%) and largely distributed in the watershed followed by the moderate/medium potentiality with 30% of the total area. The remaining zones are comprised of 20% of poor potentiality and 8% of very poor potentiality (**Figure 14**).

The good to very good zones are suitable for the implementation of groundwater supply to surface water scarcity issue and demand in a context of climate change impact and predict high exploitation rates of water from expected wells.

4.3. Validation of the GWPZs

It is essential to check the liability of the model outputs before allow the exploitation of the results. Thus, yields data of existing twenty-five (25) wells were collected over the study area to validate the different delineated GWPZs (**Figure 15**).

4.4. Cross-Validation with Wells Rate

Observed rates of 25 wells were collected and used to confirm the different GWPZs (**Figure 15**). Targeted rates were indeed set for each potential zone: greater than 15 m^3/h for the class very good, [10 to 15 m^3/h] for the class good, [5 to 10 m^3/h] for the class moderate, [3 to 5 m^3/h] for the poor class and rates less than 3 m^3/h were predicted for the very poor class.

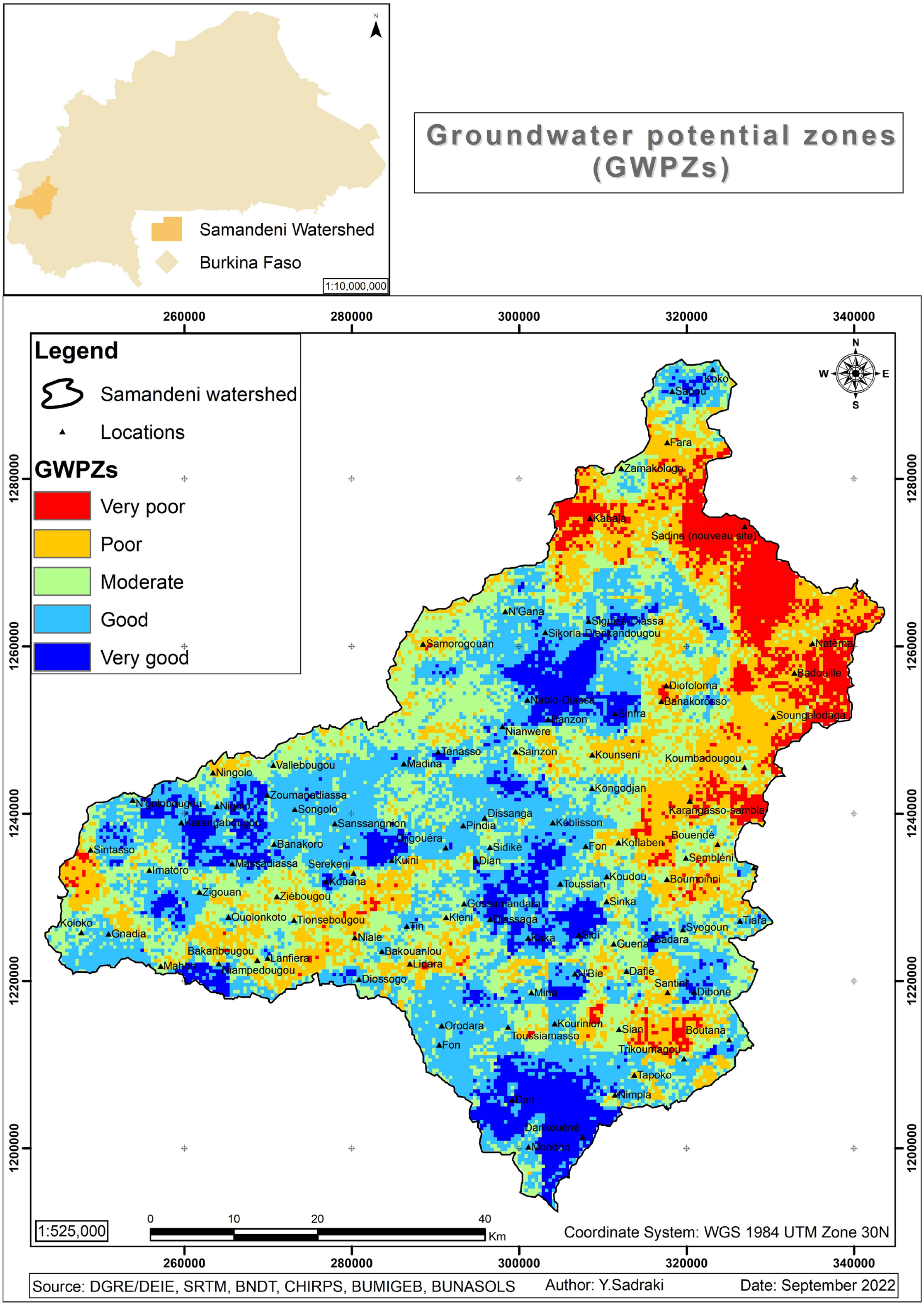

Figure 13. Groundwater potential zones (GWPZs).

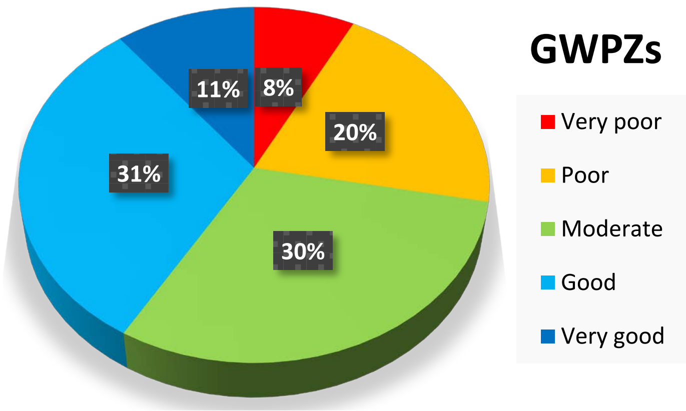

Figure 14. GWPZs statistics.

Amount the 25 validation wells overlaying the study area, 5; 6; 5; 4; 5 wells were respectively found in very good, good, moderate, poor, very poor zones. When it was come to the cross validation, it has been done by identifying the rate of each well in the targeted interval of rates of the relevant potential zone.

The validation statistics have given 5/5 rates belonging to "very good" zone and 6/6 rates to "good" zone (**Figure 16**). Most of the wells observed in "moderate" (4/5), "poor" (3/4) and "very poor" (4/5) potential zones demonstrates a fairly conformity to the respective targeted rate intervals [5 to 10 m^3/h], [3 to 5 m^3/h] and [<3 m^3/h] (**Table 5**). Better, the well F18 performed up to 50 m^3/h rate while 15 m^3/h was expected. As well the well F24 performed 3.71 m^3/h where the maximum predicted rate was 3.00 m^3/h. Hence, as highlighted by Das & Pardeshi (2018), higher rate of an aquifer indicates higher groundwater potential.

The observed flow rates from the validation wells obviously fit well with the groundwater potential zones delineated by the AHP model.

4.5. Evaluation of the Model Accuracy

The validation of the work was also made by making a simple statistical analysis of the percentage of the number of boreholes according to the flow rate classes and the sensitivity of different classes (**Table 5**).

Besides the cross-validation with the relationship between different groundwater potential zones and the wells available in the study area, another attempt has been made to verify the accuracy of the model. Based on the confusion matrix, the producers' accuracy was calculated giving 100% accuracy for "very good" and "good" GWPZs, 80% accuracy for "medium" and "very poor" classes and 75% for the poor potential zone, while, the consumers' accuracy in shown below in **Table 6**.

The overall accuracy is estimated to 88% provided from the result of the similarity analysis where 22 out of the 25 validation wells matches with the expected yield classes of GWPZs. The Kappa coefficient obtained is 0.86. Meanwhile Ranjit et al. (2021) have validated the results of a similar study with an overall accuracy of 81.25% and a Kappa coefficient of 0.72. In his side, Jhariya et al. 2016

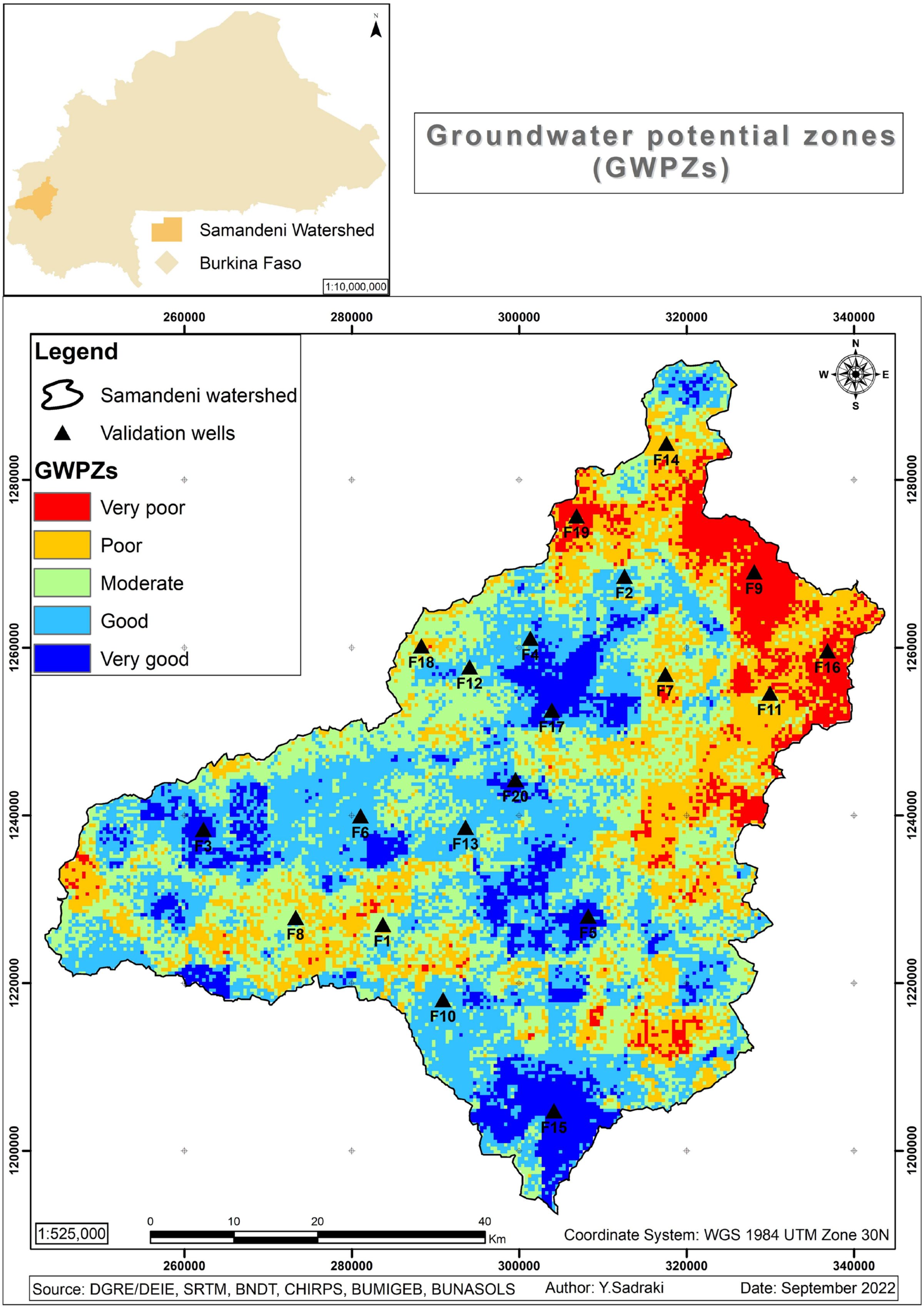

Figure 15. Distribution of the twenty (20) validation wells over the study area.

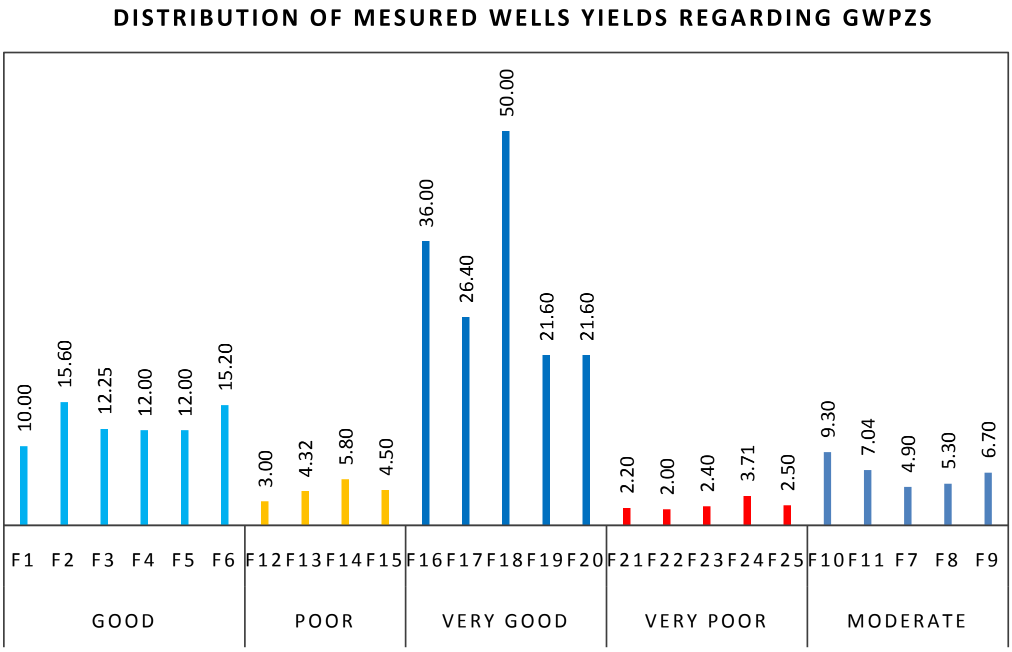

Figure 16. Wells yields distribution on the different GWPZs.

Table 5. Confusion matrix between GWPZs classes.

GWPZs	Very good [>15]	Good [10 - 15]	Medium [5 - 10]	Poor [3 - 5]	Very poor [<3]	Total
Very good [>15]	5	0	0	0	0	5
Good [10 - 15]	0	6	0	0	0	6
Medium [5 - 10]	0	0	4	1	0	5
Poor [3 - 5]	0	0	1	3	0	4
Very poor [<3]	0	0	0	1	4	5
Total	5	6	5	5	4	25

Table 6. Consumers accuracy of the GWPZs classification.

GWPZs	Percentage
Very good [>15]	100%
Good [10 - 15]	100%
Medium [5 - 10]	80%
Poor [3 - 5]	60%
Very poor [<3]	100%

justifies the efficacy of obtained result of the AHP approach in the demarcation of groundwater potential zone with 80% of accuracy. To establish a relationship between different groundwater potential zones and the wells available in Pravara basin, Das Sumit & Pardeshi Sudhakar calculated the accuracy of the model. The AUC shows 73% accuracy when the model is built using frequency ratio, while

69% accuracy with influencing factor method (Das & Pardeshi, 2018). All these statistics reveal the performance of AHP model to delineate groundwater potential zones at the scale of a watershed. Compared to the referenced previous studies the result of the current study shows amazing proficiency.

A strong validation could further involve geophysical field measurements with a complementary field observation. These geophysical measurements could indicate the potentially or even the existence of groundwater reservoirs in aquifers. This is not done here due to limited resources.

5. Discussion

Assuming that the sedimentary domain naturally stores groundwater, few studies have been carried out in Burkina Faso to identify the best areas with high groundwater potential. However, in order to obtain high yields capable of supplementing a surface water reservoir in case of dryness, it is necessary to identify specific areas with high potential. The AHP approach is used in this study to determine the different potential zones. The difficulty in determining the number of factors lies in the limitation of the number of factors that can be taken into account. According to Saaty & Vargas (1980), the choice of factors should be limited to seven per level of hierarchy. However, acknowledging the heterogeneity of the sedimentary domain of the Samendeni basin due to the multiple dolerite or granitoid intrusions, the factors considered are optimised to ten (10). These are the most significant factors that contribute to increase the productivity of drilling in porous media. The high number played a role in the calculation of the uncertainties and the confusion matrix which are of good quality.

The limitation of the method is that it assumes the values of the grid cells to be continuous, which they are not. Also, the aggregations are performed on the pixels, as if the variables were continuous from one grid cell to another.

The multicriteria analysis method for decision support has been used by many authors (Joerin, 1995; El Morjani, 2003; Jourda et al. 2006; Youan Ta et al., 2011; PAEA, 2022). It have been used to map areas that are suitable for installing high-rate boreholes (Savané, 1997; Saley, 2003) and for recharging groundwater (Ake et al., 2018), as well as for selecting the best sites for waste storage (El Moorjani 2003; Roy, 2014; Kouamé, 2007). A sobering reliability of the results could come from:

- the uneven geographical distribution of data used for the interpolation over the study area;
- the assumption that all factors are perfectly comparable. Indeed, the weighting of qualitative factor is delicate, unlike quantitative factor (Joerin 1995 in Saley 2003). However, the technique of standardising the factor facilitates and makes possible their combination;
- the non-respect of class limits as these class limits do not always follow a universal classification.

Therefore, the groundwater potential map obtained in this study could be used as an indicator for any hydrogeological prospection as suggested by Langevin et al. (1991). The validation just from the control of borehole samples by flow rates showed that the potential sites identified in the catchment area are considered relevant.

The comparison of the results with those of the AHP study underway by the PAEA at the scale of bedrock of Burkina can be made with regard to the surface proportions of the different potentiality classes. There is an order of similarity between the different potentiality classes. For example, 11% versus 10% of the very good class in the PAEA study on the base, 31% versus 21% of the good class, 30% versus 31% of the moderate class, 20% versus 25% of the poor class, 8% versus 13% of the very poor class. This not only demonstrates the consistency of the results but also reveals the close behaviour of the sedimentary domain that forms the study area on the edge of the bedrock. This can be explained by tectonic activities which must have torpedoed the sedimentary domain by shearing and fracture movements as well as by scattered injections of magma (dolerite, granitoids), hence the almost identical functioning of the basement.

6. Conclusion

The AHP model was applied to carry out this study regarding it wide use in the region of West Africa but especially due to reliable results it provides. A total of ten thematic layers, such as geology, geomorphology, LULC, drainage density, soil, and slope, piezometric level in wells, rainfall seepage water, bore wells depth and flow rate were integrated in GIS software and used to delineate the GWPZs in Samendeni watershed. They were classified into five classes as very good (11%), good (31%), moderate (30%), poor (20%), and very poor (8%). The proportion of very good and good potential zones is significant over the study area (42%). For well rate at least 10 m^3/h corresponding to those targeted zones, the study reveals the capability of groundwater to correctly supply water demand in Samendeni watershed. Whatever the climate change could affect surface water availability, groundwater remains a sustainable source of supplier. The large potential zone in the south of the study area is a great chance for population of the city of Oradara regarding the closer it is to that city. Instead of conducting in channels over 40 km the water from Samendeni dam or digging pipe to the river stream as suggested by the PDIS project to overcome water needs in the irrigation areas, drilled wells in the good potential zones could properly provide the expected water volume. By the way, that will even lead to save money, energy and environment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Abdou Ali, I., & Konaté, M. (2018). *Identification et cartographie des zones potentielles de* *recharge des eaux dans la région de Dosso (sud-ouest, Niger) par analyse multicritère.*

Abebe, D. T. (2021). Groundwater Potential Mapping Using Geospatial Techniques: A Case Study of Dhungeta-Ramis Sub-Basin, Ethiopia. *Geology, Ecology, and Landscapes, 5,* 65-80. https://doi.org/10.1080/24749508.2020.1728882

Affoué, B. Y., Bi, T. A. G., Alioune, K., Oi Mangoua, J. M., & Kouamé, A. K. (2016). *Cartographie du potentiel en eau souterraine du bassin versant de la Lobo (Centre-Ouest, Côte d'Ivoire): Approche par analyse multicritère.*

Ahmed, G., Adel, M., Ahmed, E.-G., & Magaly, K. (2020). *Mapping the Groundwater Potentiality of West Qena Area, Egypt, Using Integrated Remote Sensing and Hydro-Geophysical Techniques.*

Ake, G. E., Kouame, K. J., Koffi, A. B., & Jourda, J. P. (2018). Cartographie des zones potentielles de recharge de la nappe de Bonoua (sud-est de la Côte d'Ivoire). *Revue des sciences de l'eau, 31,* 129-144. https://doi.org/10.7202/1051696ar

Akokponhoué, Y. N., Nicaise, Y., Bertrand, H. A., Youan, T. M., & Agbahoungba, G. (2019). *Apport de la télédétection et de la géophysique dans la cartographie des fractures hydrauliquement actives en zone de socle au centre-ouest du Benin.*

Arulbalaji, P., Padmalal, D., & Sreelash, K. (2019). GIS and AHP Techniques Based Delineation of Groundwater Potential Zones: A Case Study from Southern Western Ghats, India. *Scientific Reports, 9,* Article No. 2082. https://doi.org/10.1038/s41598-019-38567-x

Babayé, M. S. (2012). *Evaluation des ressources en eau souterraine dans le bassin de Dargol (Liptako Niger)* (p. 235). PhD Thesis, Université Liège.

Boko, M., Adjakpa, T. Th., & Sedjame, R. A. (2017). *Les facteurs naturels et le forçage anthropique des inondations en zone sahélienne dans le bassin du Niger au Benin (Afrique de l'ouest)* (Vol. 1, pp. 77-83). Numéro spécial COP22.

Choudhari, K., Panigrahi, B., & Paul, J. C. J. (2014). Morphometric Analysis of Kharlikani Watershed in Odisha, India Using Spatial Information Technology. *International journal of Geomatics and Geosciences, 4,* 661-675.

Dakoure, D. (2003). *Etude hydrogéologique et géochimique de la bordure sud-est du bassin sédimentaire de Taoudeni (Burkina Faso-Mali): Essai de modélisation.* Thèse.

Das, S., & Pardeshi, S. D. (2018). Integration of Different Influencing Factors in GIS to Delineate Groundwater Potential Areas Using IF and FR Techniques: A Study of Pravara Basin, Maharashtra, India. *Applied Water Science, 8,* 197. https://doi.org/10.1007/s13201-018-0848-x

Derouane, J. (2008). *Étude hydrogéologique et modélisation mathématique du système aquifère du bassin sédimentaire de Taoudenni au Burkina Faso.*

Derouane, J. (2010). *Étude hydrogéologique et modélisation mathématique du système aquifère du bassin sédimentaire de Taoudéni au Burkina Faso.*

Detay, M., & Poyet, P. (1991). *Techniques modernes d'action sur les eaux souterraines, bilan et perspectives.* Rapport général de la question II des XXIe journées de l'hydraulique. Colloque de la société hydrotechnique de la France, G.G.II.1-13.

El Morjani, Z. (2003). *Conception d'un système d'information à référence spatiale pour la gestion environnementale; application à la sélection de sites potentiels de stockage de déchets ménagers et industriels en région semi-aride (Souss, Maroc)* (300 p.). Thèse de Doctorat, Université de Genève.

Fabrice, K. N. et al. (2020). Apport Des Nappes Profondes À L'amélioration De La Desserte En Eau De Consommation Dans Le Bassin Versant Du Kan (Côte d'Ivoire). *European Scientific Journal, ESJ, 16,* 260. https://doi.org/10.19044/esj.2020.v16n24p260

Haouchine, A., Boudoukha, A., Fatima, Z. H., & Rachid, N. (2010). Cartographie de la recharge potentielle des aquifères en zone aride. *Eurojournals, 45,* 1-13.

Huneau, F., Dakoure, D., Celle-Jeanton, H., Vitvar, T., Ito, M., Traore, S., Compaore, N.F., Jirakova, H., & Le Coustumer, P. (2011). Flow Pattern and Residence Time of Groundwater within the South-Eastern Taoudeni Sedimentary Basin (Burkina Faso, Mali). *Journal of Hydrology, 409,* 423-439. https://doi.org/10.1016/j.jhydrol.2011.08.043

Hyann, P., Naga, C., Honoré, C. T. J., & Issiaka, S. (2015). Cartographie des potentialités en eaux souterraines par l'utilisation de l'analyse multicritère et les SIG: Cas du district du Denguélé (Nord-Ouest de la côte d'ivoire). *European Scientific Journal, ESJ, 11.*

INSD (2006). *Recensement général de la population et de l'habitat. Annuaire statistique du Burkina Faso.*

IPCC (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.*

Jha, M. K., Chowdary, V. M., & Chowdhury, A. (2010). Groundwater Assessment in Salboni Block, West Bengal (India) Using Remote Sensing, Geographical Information System and Multi-Criteria Decision Analysis Techniques. *Hydrogeology Journal, 18,* 1713-1728. https://doi.org/10.1007/s10040-010-0631-z

Jhariya, D. C., Kumar, T., Gobinath, M., Diwan, P., & Kishore, N. (2016). Assessment of Groundwater Potential Zone Using Remote Sensing, GIS and Multi Criteria Decision Analysis Techniques. *Journal of the Geological Society of India, 88,* 481-492. https://doi.org/10.1007/s12594-016-0511-9

Joerin, F. (1995). Méthode multicritère d'aide à la décision et SIG pour la recherche d'un site. *Revue internationale de géomatique, 5,* 37-51.

Jourda, P., Saley, M. B., Djagoua, E. M., Kouamé, K. J., Biémi, J., & Razack, M. (2006). Utilisation des données ETM+ de Landsat et d'un SIG pour l'évaluation du potentiel en eau souterraine dans le milieu fissuré précambrien de la région de Korhogo (Nord de la Côte d'Ivoire): Approche par analyse multicritère et test de validation. *dans Revue Internationale de Télédétection, 5,* 339-357.

Kafando, S. (2020). *Caractérisation hydrogéologique et potentialités en eau souterraine: Cas de la feuille de Ouagadougou.* Thèse, Université de Ouagadougou.

Koffi, A. B. (2016). *Détermination des zones de recharge de la nappe de Bonoua: Approche cartographique et SIG* (70 p.). Mémoire de Master, Université Felix Houphouët Boigny.

Kouamé, K. J. (2007). *Contribution à la gestion intégrée des ressources en eaux (GIRE) du District d'Abidjan (Sud de la Côte d'Ivoire): Outils d'aide à la décision pour la prévention et la protection des eaux souterraines contre la pollution* (222 p.). Thèse de Doctorat, Université de Cocody.

Kouanda, B. (2019). *Modélisation Intégrée du Complexe Mouhoun supérieur-Sourou dans le contexte des changements climatiques.* Thèse de doctorat.

Koudou, A., Adiaffi, B., Assoma, T. V., Sombo, A., Amani, E. M. E., & Biemi, J. (2013). Conception d'un outil d'aide à la décision pour la prospection des eaux souterraines en zone de socle du sud-est de la Côte d'Ivoire. *Geo-Eco-Trop, 37,* 211-226.

Koussoubé, Y. (1996). *Hydrogéologie en milieu de socle cristallin du Burkina Faso. Cas du bassin versant du bas-fond de Bidi (province du Yatenga)* (263 p.). Thèse de doctorat, Université Cheikh Anta Diop de Dakar (Sénégal).

Koussoube, Y. (2010). *Hydrogéologie des séries sédimentaires de la dépression piézométrique du Gondo (bassin du Sourou): Burkina Faso/Mali.* Hydrologie. Université Pierre et Marie Curie—Paris VI, Français.

Kumar, R., Singh, R. D., & Sharma, K. D. (2005). Water Resources of India. *Current Science, 89,* 794-811.

Langevin, C., Pernel, F., & Pointet, T. (1991). Aide à la décision en matière de prospection hydrogéologique. L'analyse multicritère au service de l'évaluation du potentiel aquifère, en milieu fissuré (granite de Huelgoat, Finistère, France). *Hydrogéologie, 1,* 51-64.

Malundama, S. K. (2019). *Caractérisation hydrogéologique des aquifères du bassin sédimentaire de Taoudéni (bordure sud-est, Burkina Faso).* Thesis.

Melese, T., & Belay, T. (2021). Groundwater Potential Zone Mapping Using Analytical Hierarchy Process and GIS in Muga Watershed, Abay Basin, Ethiopia. *Global Challenges, 6,* Article ID: 2100068. https://doi.org/10.1002/gch2.202100068

Mohamed, M. M. S., & Imad, F. (2021). Integrating GIS-Based FAHP and WaTEM/SEDEM for Identifying Potential RWH Areas in Semi-Arid Areas. *Geocarto International,* 1-24.

Mukherjee, S., Aadhar, S., Stone, D., & Mishra, V. (2018). Increase in Extreme Precipitation Events under Anthropogenic Warming in India. *Weather and Climate Extremes, 20,* 45-53. https://doi.org/10.1016/j.wace.2018.03.005

Nakolendoussé, S. (1991). *Méthode d'évaluation de la productivité des sites aquifères au Burkina Faso: Géologie, géophysique, télédétection.* Thèse, Université Joseph Fourier.

PAEA (2022). *Etude d'identification de zones aquifères favorables par l'analyse multicritère, d'implantation de forages productifs en zone de socle et contrôle de réalisation de forages, Burkina Faso.* Rapport.

Ranjit, M., Dhoni, B., Gibji, N., Oyi, D. N., & Ramesh, C. J. (2021). *AHP and GIS-Based Delineation of Groundwater Potential of Papumpare District of Arunachal Pradesh, India.* https://doi.org/10.21203/rs.3.rs-350312/v1

Roy, A. (2014). Availability, Scarcity and Potentiality of Groundwater Resources in Puruliya District of West Bengal: An Appraisal. *International Journal of Scientific Footprints, 2,* 78-93.

Saaty, T. L. (1977). A Scaling Method for Priorities in Hierarchical Structures. *Journal of Mathematical Psychology, 15,* 234-281. https://doi.org/10.1016/0022-2496(77)90033-5

Saaty, T. L. (2008). Decision Making with the Analytic Hierarchy Process. *International Journal of Services Sciences, 1,* 83-98. https://doi.org/10.1504/IJSSCI.2008.017590

Saaty, T. L., & Vargas, L. G. (1980). Hierarchical Analysis of Behavior in Competition: Prediction in Chess. *Behavioral Science, 25,* 180-191. https://doi.org/10.1002/bs.3830250303

Saïdou, G. I., Koussoube, Y., Saley, A., Sandao, I., Hayes, P., & Ousmane, B. (2019). Groundwater Flow Modeling by Using the Permeability Induced by Satellite Lineaments in Discontinuous Aquifers and Semi-Arid Context: A Case Study of the Liptako Region (South-West of Niger). *Journal of Water Resource and Protection, 11,* 1090-1109. https://doi.org/10.4236/jwarp.2019.118064

Saley, M. B. (2003). *Système d'informations hydrogéologiques à référence spatiale, discontinuités pseudo-image et cartographies thématiques des ressources en eau de la région semi-montagneuse de Man (Ouest de la Côte d'Ivoire)* (211 p.). Thèse de doctorat de l'Université de Cocody-Abidjan, Côte d'ivoire.

Sauret, E. (2013). *Contribution à la compréhension du fonctionnement hydrogéologique du système aquifère dans le bassin du Kou.* Mémoire.

Savadogo, N. (1984). *Géologie et hydrogéologie du socle cristallin de Haute-Volta: Étude régionale du bassin versant de la Sissili* (179 p.). Thèse de doctorat, Université scientifique et médicale de Grénoble (France).

Savané, I. (1997). *Contribution à l'étude géologique et hydrogéologique des aquifères discontinus du socle cristallin d'Odienné (Nord-Ouest de la Côte d'Ivoire). Apports de la télédétection et d'un Système d'Information Hydrogéologique à Référence Spatiale* (386 p.). Thèse de Doctorat d'Etat ès Sciences Naturelles, Université d'Abidjan.

Sekoube, O., Fernand, K. K., Mahaman, B. S., Gabriel, E. A., Germain, M. A., Alexis, K. K., & René, T. (2014). Estimation et validation de la profondeur des nappes du bassin du N'zo, en Côte d'Ivoire, par le modèle WTR. *Physio-Géo, 8,* 1-25. https://doi.org/10.4000/physio-geo.3752

Sinclair Knight Merz (2009). *Adaptation Options for Climate Change Impacts on Groundwater Resources*. Victoria.

Singh, L., Katpatal, Y., & Artic, J. (2018). A GIS-Based Multi-Criteria Decision Analysis Approach for Public School Site Selection in Surabaya, Indonesia. *Journal of Urban and Environmental Engineering, 12,* 70.

Thaís, P. B., Luis, A. P. et al. (2020). Assessment of the Groundwater Favorability of Fractured Aquifers from the Southeastern Brazil Crystalline Basement. *Hydrological Sciences Journal, 65,* 442-454. https://doi.org/10.1080/02626667.2019.1703993

Tirogo, J. (2016). *Etude du fonctionnement hydrodynamique de l'aquifère sédimentaire du bassin du Kou au sud-ouest du Burkina Faso Hydrogéologie*. Thèse.

Yao, A. B., Goula, B. T. A., Mangoua, O. M. J. et al. (2016). Cartographie du potentiel en eau souterraine du bassin versant de la Lobo (Centre-Ouest, Côte d'Ivoire): Approche par analyse multicritère. *Hydrological Sciences Journal, 61,* 856-867. https://doi.org/10.1080/02626667.2014.932360

Youan Ta, M., Lasm, T., Jourda, J. P., Saley, M. B., Adja, G. M., Kouame, K., & Biemi, J. (2011). Cartographie des eaux souterraines en milieu fissuré par analyse multicritère: Cas de de la région de Bondoukou (Côte-d'Ivoire). *Revue Internationale de Géomatique, 21,* 43-71. https://doi.org/10.3166/rig.21.43-71

Youan Ta, M., Yao, K. A. F., Bakar, D., De Lasm, Z. O., Lasm, T., Adja, M. G., Kouakou, S., Onetie, Z. O., Jourda, J. P. R., & Biemi, J. (2015). *Cartographie des zones potentielles à l'implantation des forages à gros débits en milieu fissure par analyse multicritère cas du département d'Oumé (centre-ouest de la cote d'ivoire).*

Zougmoré, F., Damiba, L., D'Haen, S., & Dayamba, S. D. (2019). *État des connaissances scientifiques sur les ressources en eau au Burkina Faso et de l'impact des changements climatiques sur ces ressources. Report produced under the project "Projet d'Appui Scientifique aux processus de Plans Nationaux d'Adaptation dans les pays francophones les moins avancés d'Afrique subsaharienne".* Climate Analytics gGmbH.